Juvenile American Shad Assessment in the Lower Vernon Dam Pool
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Introduction

American shad are considered to be under restoration in the Connecticut River basin and are jointly managed under the auspices of the Connecticut River Atlantic Salmon Commission (CRASC) which includes the Directors of the Fish and Wildlife agencies of the States of Vermont, New Hampshire, Massachusetts and Connecticut as well as the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (Regional Directors). The CRASC has an approved "Management Plan for American Shad in the Connecticut River Basin," that identifies seven management objectives (CRASC 1992). Three of the seven objectives include:

- Achieve and sustain an adult population of 1.5 to 2.0 million individuals entering the mouth of the Connecticut River.
- Achieve annual passage of 40 to 60% of the spawning run (based on a 5 year running average) at each successive upstream barrier on the Connecticut River main stem.
- Maximize outmigrant survival for juveniles and spent shad.

In addition, the Atlantic States Marine Fisheries Commission (ASMFC) has responsibility for the development, approval, and enforcement of coast-wide migratory species plans as well as state fisheries regulations and required population monitoring that include American shad. Like the CRASC, the ASMFC was approved by both the U. S. Congress and the States.

Vernon Dam is located at river mile 142 and is the third main stem dam, located in Vernon Vermont. Based on the CRASC Shad Plan goal of 1.5 to 2.0 million adults entering the river mouth, the upstream shad passage target (not accounting for any removal by in-river fisheries) would range from 96,000 to 432,000 shad passing upstream of Vernon Dam. The Vernon Dam fish ladder has been in operation since 1981 and has passed an average of 5,266 adult shad annually (range 9 to 37,197).

To maximize both juvenile and spent adult shad outmigrant survival, important fish passage concerns must be addressed, including; physical injury, mortality, delays, and physiological stressors. One potential source of physiological stress and or delay is thermal waste water discharge related to power production. In the situation of the Vernon Hydroelectric Project, existing downstream fish passage facilities are located on the same river bank (western shoreline) as the Vermont Yankee Nuclear Power Station (VY). VY's heated effluent is discharged approximately 0.45 miles upstream of the Vernon Dam. The National Pollution Discharge Elimination System (NPDES) permit currently in effect for VY allows the river temperature to be raised by as much as 13.4°F for the period October 15 through May 15 (defined as the "Winter" VY thermal period). Compliance with this limit is partially determined at a location approximately 0.6 miles downstream (VY Station #3) of the Vernon Dam and is also based upon a thermodynamic formula that uses measured ambient river temperature at a location upstream from VY to calculate the amount of allowable heat output from the plant, with model assumptions on subsequent heat dissipation. There are no sub-hourly continuous monitoring data on what the actual discharge temperature is and how the discharge plume varies in its characteristics dependent on a suite of dynamic variables that can change on an hourly basis (i.e., Vernon Station operations, impounding, generation). With a permitted whole river increase of up to 13.4°F, the discharge plume temperature can be substantially greater in its magnitude in relation to when later (time) and further downstream (space) it is considered "fully mixed," 0.6 miles below Vernon Dam, the only actual VY full-year temperature monitoring point for compliance downstream of the VY discharge point.

Thermal limits for VY are also in place for the "Summer" VY thermal period (defined as May 16 through October 14), when the plant is allowed to increase river temperature from 2–5°F, depending on ambient conditions as measured 3.5 miles upstream of the plant. The juvenile American shad fish passage outmigration period (i.e., when fishways at hydropower projects must be operated) is determined by the CRASC agencies, and required by law under the Federal Energy Regulatory Commission. The current period for juvenile American shad downstream passage operation for the Vernon Station (subject to change) is August 1 through November 15, that includes VY's permitted "Winter" thermal increased period. Depending on the timing and duration of juvenile shad outmigration from upstream of the Vernon Dam, fish may be expected to encounter a heated discharge plume that due to the dynamic conditions of river flow, Vernon Station operations, and other factors, result in changing variables (i.e., timing, magnitude, duration of exposure) of the plume and elevated river temperatures (i.e., periods of dam impounding water). A 2003 report by a VY consultant states that the full capacity plant thermal discharge is 488 million gallons per day, which translates to 800 cubic feet a second with temperatures as high as 100° F (Normandeau 2003). While no site specific studies have been conducted relative to the potential impact VY's heated discharge plume and increase of river temperature on juvenile American shad behavior, physiology, route selection, delay, passage choice, and survival, studies have been published relative to temperature effects on behavior and migration delay effects on survival (Moss 1970; Zydlewski et al. 2003).

In September 2012, a study was developed with the goal of determining juvenile shad abundance and near surface water temperature in the vicinity of VY and Vernon Dam (lower Vernon Dam Pool). The study objectives included assessing: 1) relative abundance of juvenile American shad at fixed transect locations in the Lower Vernon Pool (LVP); 2) juvenile shad size (total length); and 3) water temperatures from fixed locations upstream of VY downstream to the forebay area of Vernon Dam. Collected data are compared and contrasted over time.

Methods

A Smith Root (SR-18-ft) electrofishing boat, with twin bow anode booms, a 16 dropper umbrella array on each boom, and the boat hull serving as the cathode was the sampling platform. A 5,000 watt generator supplied power to the Gas Powered Pulsator on the boat. Effort was standardized with two people netting off the bow deck of the boat with long handled dip nets of small mesh size (#44 Delta mesh). Anode dropper arrays were located slightly off center of the bow line and to an angle which maximized single cable dropper exposure in the water column, while keeping the anode frame above the waterline. The electrofisher was set to fish at High Range, 60 PPS (pulses per second, DC) at 60-80% of Range, which resulted in a measured amperage output of between 6 – 7 amps. The electrofisher's "on-meter" records the time power is applied. A sample period time, based on applied power, of 500 seconds was the designated time of sampling effort. The electrofisher's power was applied in a systematic "on" and then a "rest" period (approximate 5 second intervals) as the boat was slowly moved in a downstream direction, to prevent pushing fish ahead of the boat and its electric field. Boat electrofishing was initiated once the sun was near setting and ambient light conditions were reduced. Juvenile shad were netted off the bow, by two netters, and placed in a container for processing (identification, enumeration, and total length) at the completion of each sampling run. Catch-per-unit of effort was derived and reported as juvenile shad captured per minute of sampling effort.

Four near-shoreline sampling transects were identified and logged into a Garmin GPS 76CSx global positioning unit. Sites were selected based upon proximity to the Vernon Dam downstream fishways and Vermont Yankee's thermal discharge and proximal locations both upstream and downstream of the VY discharge (Figure 1 and 2).

Water temperature was measured along transects at a series of sites across the main stem channel that were identified and logged into the GPS unit. These sample locations were selected to represent areas upstream of the VY thermal discharge, in proximity to the discharge, and also downstream of the discharge to the Vernon Dam (Figure 1 and 2). Water temperatures were collected using a Yellow Springs Instruments Model 85 Multimeter at a depth of 3 feet below the water surface. The YSI meter was checked in a laboratory setting with a current certified National Institute of Standards thermometer at room temperature and in an ice bath to ensure accuracy. Field measurements of water temperature were taken off the bow deck of the electrofishing boat starting at the most upstream site (011) and progressing in sequence to the most downstream site close to the Vernon Dam forebay (033) for a total of 23 measurements. Temperature readings were recorded following a period of stabilization in the river (2 minutes typically). Temperature samples were taken after 3:00PM on all events, prior to fish sampling. Beginning in the dusk time period, fish sampling was initiated, with the first run starting in close proximity to the final temperature reading location (033).

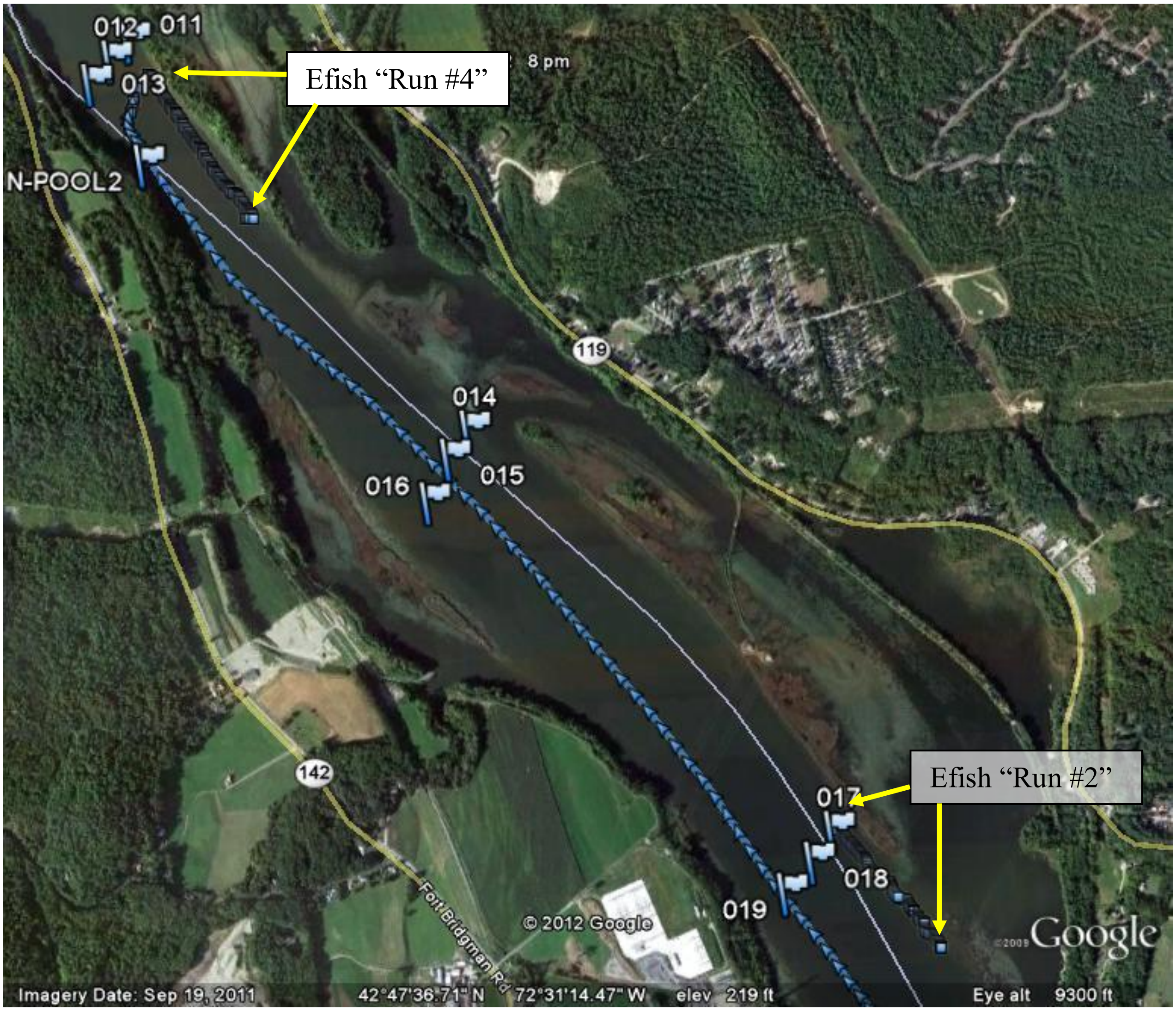

Figure 1. Locations of upstream water temperature transect measurements (011 through 019 flags) and juvenile shad boat electrofishing survey runs #4 and #2 shown. Temperature sites 017, 018, and 019 are located offshore of the Vermont Yankee Station.

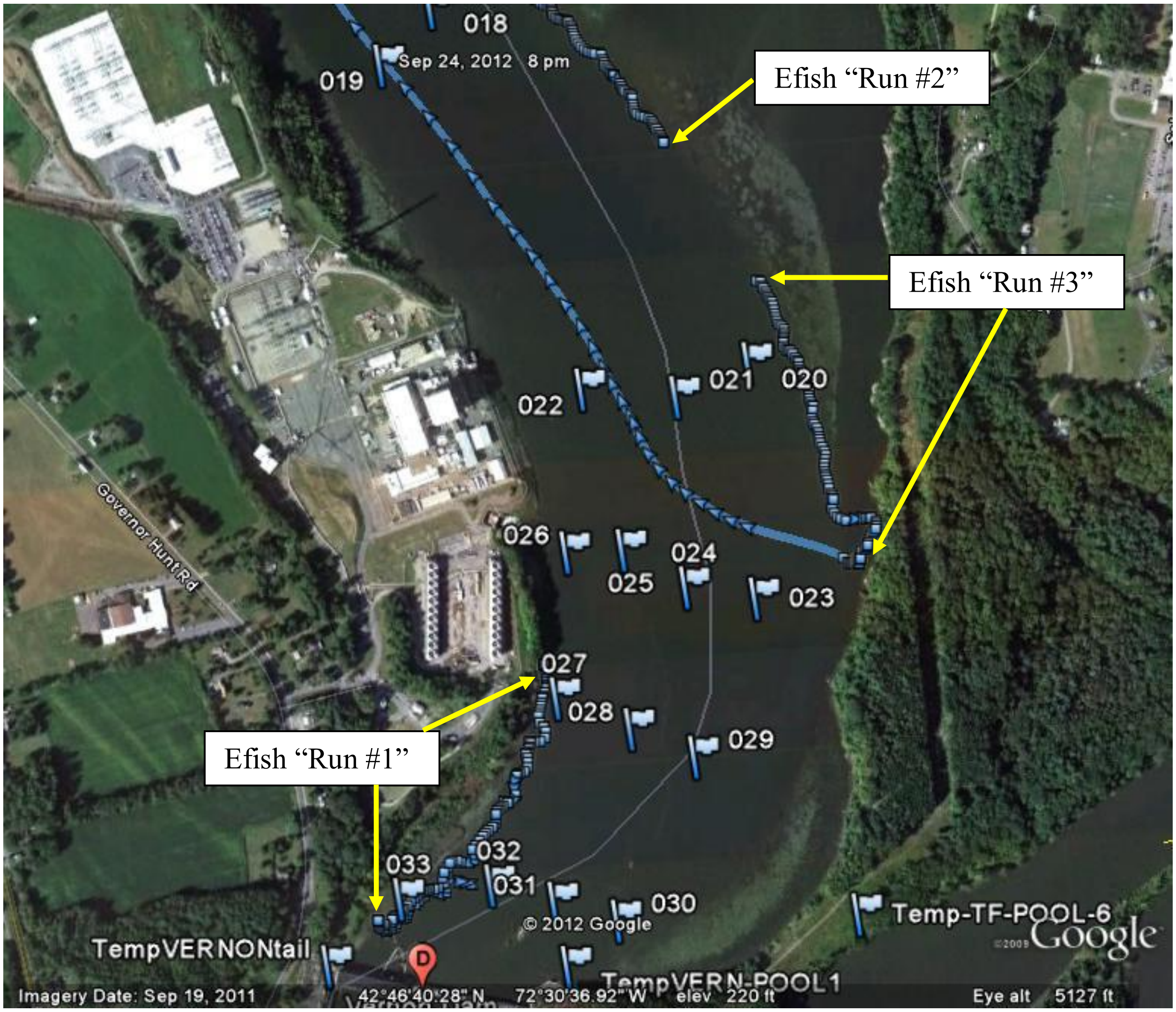

Figure 2. Locations of water temperature transect measurements and juvenile shad boat electrofishing survey transects. Temperature site 026 is just offshore of VY discharge point for reference. The end of Run 1 electrofishing transect is immediately upstream of cabled trash booms in forebay of Vernon Station intakes, location of downstream fishways.

Results

The assessment of water temperature and juvenile American shad was completed on four dates; September 24, October 11, October 18, and October 25, 2012. Observed water temperatures at identified sites, taken from a depth of 3 feet, are provided in Table 1. A temperature gradient was documented from sites upstream of Vermont Yankee, to sites located downstream, as a result of thermal discharge from the plant, which was observed as active on all four sampling events. Additional physical parameters such as instantaneous river flow and water velocity were not measured due to the limited scope of this short-term study which only could provide four brief “snap shots” of water temperatures. Both flow and velocity in the study area are affected by factors including turbine operations at both the Vernon Dam and the Bellow Falls Dam located upriver, and inflow from the various tributaries located between the two dams (West River, Saxtons River, Cold River, and other smaller brooks).

Table 1. Water temperature measures °F at identified sites, taken from a depth of 3 feet, in the Lower Vernon Pool, 2012.

Site	9/24	10/11	10/18	10/25
11	66.2	58.8	55.0	53.4
12	66.4	58.6	54.9	53.4
13	66.2	58.6	54.3	53.6
14	65.8	58.5	55.4	53.4
15	66.2	58.6	55.2	53.4
16	66.4	58.6	54.7	53.4
17	66.0	58.6	55.8	53.4
18	66.0	58.6	55.6	53.6
19	66.0	58.6	54.5	53.6
20	66.0	58.5	58.5	55.6
21	66.2	58.6	56.3	53.6
22	66.0	58.6	55.2	53.6
23	68.2	58.5	59.4	55.4
24	66.2	58.6	58.6	57.2
25	68.7	58.6	59.2	56.3
26	71.6	65.1	64.4	59.2
27	69.1	61.2	63.0	61.3
28	70.9	61.9	63.7	58.3
29	68.2	58.6	63.0	57.9
30	70.3	62.1	61.9	59.9
31	70.0	61.9	60.8	59.5
32	68.9	60.6	60.3	58.8
33	70.0	61.2	62.8	58.8

Juvenile American shad sampling electrofish sampling yielded a total of 360 fish over the four sample dates, with a general decline in total numbers over the period and variable catches observed among the four sampling sites (Table 2). The Run 1 site had the highest mean catch rate and overall juvenile shad catch over the four sample dates and was located along the western river bank from the VY discharge to the Vernon Station forebay. On all sampling occasions, a relatively large amount of surface “popping” by juvenile shad was documented, including digital movie images, showing this unique behavior, particularly in the area between the VY discharge and the Vernon Dam forebay at dusk (Kynard and Theiss 2003). The largest sample capture event occurred at site Run 2 on September 24. The lowest catches, none observed or caught, occurred on the last sample date, October 25, at sites Run 3 and Run 4. The river was very turbid on October 25 and conditions may have affecting shad catch rates due to reduced visibility for the netters.

Table 2. Number of juvenile American shad captured by site and date in the lower Vernon Dam pool, from upstream to downstream sample locations.

	Site					
Date	Run 4	Run 2	Run 3	Run1	Mean	Total
9/24/12	18	77	10	65	42.5	170
10/11/12	1	23	15	44	20.8	83
10/18/12	3	25	14	51	23.3	93
10/25/12	0	1	0	13	3.5	14
Mean	5.5	31.5	9.8	43.3		
Total	22	126	39	173		360

Mean juvenile shad CPUE, as expressed in fish-per-minute, ranged from 0.0 to 9.2 among the four sites over the four dates (Table 3). A test to examine whether CPUE decreased through time at the same rate among sites was conducted. An analysis of covariance was used with sites used as the covariate and CPUE data were log+1 transformed before running the ANCOVA. A significant difference was detected among days of the year ($P = 0.003$) as well as among sites ($P = 0.008$). The interaction between site and date was non-significant ($P = 0.397$).

Table 3. Electrofishing catch-per-unit effort, expressed in fish per minute, for juvenile shad by date and sample location, from upstream to downstream sample locations.

	Site					
Date	Run 4	Run 2	Run 3	Run1	Mean	S.D.
9/24/12	2.2	9.2	1.2	7.8	5.1	4.0
10/11/12	0.1	2.8	1.8	5.3	2.5	2.2
10/18/12	0.4	3.0	1.7	6.1	2.8	2.5
10/25/12	0.0	0.1	0.0	1.6	0.4	0.8
Mean	0.7	3.8	1.2	5.2		
S.D.	1.0	3.9	0.8	2.6		

Mean juvenile shad lengths by sample date, all Runs combined, ranged from 80.7 mm on 24 September to 92.0 mm on 18 October (Table 4). A one way Analysis of Variance procedure detected significant differences ($P < 0.05$) among possible combined date comparisons of mean fish length, identified in Table 4.

Table 4. Mean juvenile shad total lengths by date.

Date	N	Mean T.L. (mm)	S.D.	ANOVA $P < 0.05$
9/24/12 (a)	128	80.7	7.2	b, c, d
10/11/12 (b)	83	86.9	7.3	a, c, d
10/18/12 (c)	93	92.0	8.5	a, b
10/25/12 (d)	14	88.1	6.8	a

Discussion and Management Recommendations

This short-term study obtained some baseline data on the relative abundance and size structures of juvenile American shad and water temperatures data in the lower Vernon Dam Pool, in the vicinity of the Vermont Yankee thermal discharge. A 2003 VY report states that at full capacity, the plant's thermal discharge is 488 million gallons per day, which translates to 800 cubic feet a second with temperatures as high as 100° F (Normandeau 2003). The response(s) of juvenile shad to this heated water is unknown and cause for possible management concerns relative to potential population impacts.

As mentioned earlier, these concerns relate to unknown routes of passage for juveniles, the extent in time, space, and magnitude of exposure to heated water, and the possible outcome(s) of those experiences relative to juvenile shad outmigration (e.g., delays, guidance, survival and physiology). Another potential issue in relation to the heated discharge plume is the potential for elevated dissolved gas levels (total gas pressure –TGP) as discussed in detail in Weitkamp and Katz (1980). There are no data for TGP in this area and, should it be present (extent, timing, duration), what effects it may have on juvenile shad among others species and lifestages. Weitkamp and Katz (1980) state, "…*super saturation should be considered any time aquatic organisms may be exposed to heated water. This includes cooling waters of large industrial facilities*." They also describe impacts to fishes include gas bubble disease, which in worst cases results in mortality events, and impacted physiology. A 110% TGP level was cited as a level of concern. It is also important to note the tolerance of fish species to dissolved gas super saturation is not the same at all life stages or among species (Weitkamp and Katz 1980).

Studies requested by the agencies but yet to be conducted by VY include examining the timing, duration, and magnitude of thermal exposure, and routes taken or directed to, or by, this thermal plume for juvenile American shad. In other words, how do juvenile shad react as they encounter this plume, or the plumes subsequent transitioning and mixing effects in the Vernon Dam tailrace and further downstream? While this study was not able to address these questions, it did identify some limited baseline data, in near-shore habitats, relative to juvenile American shad abundance, distribution and their biological characteristics over four dates. The study showed a consistent and relatively high concentration of juvenile American shad occur during the outmigration period in an area most susceptible to both receiving and maintaining elevated VY discharge water temperatures, between the VY discharge point and the Vernon Station. The temperature data obtained in this study were limited in temporal coverage, and are not considered representative of the full range of values that may occur under various scenarios of flow and other variables (e.g., dam operations). However, they do provide some limited context as to relative changes among locations, under the conditions the measures were taken (for examples of field temperature data under more varied Fall scenarios refer to Aquatec 1977).

The Vernon Dam power house station is the location juvenile shad must move towards to utilize the downstream fish passage structures, which are surface orientated. In support of a potential concern a 1977 Vermont Yankee report states, "…*if the fishway is near the Vermont shore, the plume would have to be negotiated by the fish if they remain near the surface*" (Aquatec 1977). That statement was made relative to upstream migrating adult fish, prior to Vernon fishway construction, but also applies to juveniles passing through the same area(s).

It is unknown how juvenile American shad upstream and downstream of Vernon Dam are affected by the elevated water temperatures from both the VY discharge and the dam impoundment, particularly in the Fall, as river temperatures naturally begin to decline. River conditions including Vernon Dam operations have changed over time, including a 54% increase in turbine discharge capacity effective in 2008 as well as statistically determined increasing trends in Fall monthly mean water temperatures from VY's Station 7 data (Sprankle 2013). Research on juvenile shad outmigration over a three year period at Holyoke Dam, found decreasing water temperature determined the time migration began and ended. O'Leary and Kynard (1986) found the juvenile shad outmigration began at 19°C (66.2°F), peaked at 14-9°C (57.2°F – 48.2°F) and ended at 10-8°C (50°F – 46.4°F) In particular, questions need to be answered on whether juvenile outmigrants are affected behaviorally (e.g., delay) and physiologically, when encountering the discharge plume as normal river temperatures are declining in the Fall and VY's increased "Winter" VY thermal limits are permitted.

Research on juvenile shad has shown impacts on behavior (e.g., avoidance) with exposure to rapidly elevated temperatures (Moss 1970). Moss (1970) experimentally showed a significant change in juvenile American shad distribution to areas away from water heated 4.5°C (8°F). While a concern exists for the thermal increases during the "Summer" VY thermal limits, concerns over thermal increases for the "Winter" VY thermal limits (starting October 15) are greater given the potential 6.7 fold increase in water temperatures (if at 2°F to 13.4°F) during the juvenile shad outmigration period. As noted earlier the juvenile shad outmigration fishway operational period at Vernon Dam extends until November 15. This potential increase does not accurately reflect the extent or magnitude of actual temperature change that one can expect to occur from the VY discharge to the compliance monitoring site, a distance of 0.6 miles downstream of Vernon Dam. Zydlewski et al. (2003) showed that late season migrants faced a greater physiological challenge than do early fish. The researchers state that, "*the temperature differences experienced by early and late fish are also likely to contribute to the disparity in physiological responses by directly affecting biochemical processes as well as through physiological shifts associated with thermal acclimation*."

The ASMFC Amendment # 3 to the Interstate Fishery Management Plan for Shad and River Herring (American Shad Management) approved in 2010, identifies the goal to "*Protect, enhance, and restore Atlantic coast migratory stocks and critical habitat of American shad in order to achieve levels of spawning stock biomass that are sustainable, can produce a harvestable surplus, and are robust enough to withstand unforeseen threats*." This Plan also identifies the following objectives: Maximize the number of juvenile recruits emigrating from freshwater stock complexes; and restore and maintain spawning stock biomass and age structure to achieve maximum juvenile recruitment. This Plan provides specific Recommendations which include: Reduce the amount of thermal effluent into rivers and require a thermal zone of passage for fish migration and movement.

An important management value for juvenile shad produced in the most upstream section of their historic range of distribution (Vernon Dam to Bellow Falls) is population resilience. This most upstream habitat area and the juveniles produced there may help buffer against unforeseen environmental, anthropogenic, or other events that may be limited to the lower main stem habitat. Although this relatively short duration study was focused on juvenile American shad, similar concerns exist for adult shad on their upstream migration and spent (spawned out) adults on their downstream migration. Concerns on potential impacts from the current permitted temperature increases and Vernon Dam operations, relative to the timing, duration, magnitude of exposure, effects on route selection, behavior, energetics, physiology (e.g., fishway entrance attempts), and rate of gonad maturation have yet to be addressed under current operational conditions (both Vernon Dam and Vermont Yankee).

The current scope and objectives of the VY biological monitoring program are important, but do not and cannot serve as tools or sources of information to adequately address the concerns noted in this report. The noted concerns and questions presented in this report will require very specific and specialized study designs to begin to address these questions before any conclusions on whether or not a biological effect is occurring regarding the VY thermal discharge as currently permitted.

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References Cited

Aquatec. 1977. The effects of the thermal discharge from Vermont Yankee on fishway water temperatures. Burlington, Vermont.

ASMFC. 2010. Amendment 3 to the interstate fishery management plan for shad and river herring (American shad management). Atlantic States Marine Fisheries Commission, Washington, D.C.

CRASC. 1992. A management plan for American shad in the Connecticut River basin. Connecticut River Atlantic Salmon Commission, Sunderland, MA.

Duston J., R. L. Saunders, and D. E. Knox. 1991. Effects of increases in freshwater temperature on loss of smolt characteristics in Atlantic salmon (Salmo salar). Canadian Journal of Fisheries and Aquatic Science: Vol. #48: 164-169.

Glebe, B. D. and W. C. Leggett. 1981. Latitudinal differences in energy allocation and use during the freshwater migration of American shad and their life history consequences. Canadian Journal of Fisheries and Aquatic Sciences 38, 806-820

Jonsson, B. and J. Rudd-Hansen. 198. Water temperature as the primary influence on timing of seaward migration of Atlantic salmon (Salmo salar) smolts. Canadian Journal of Fisheries and Aquatic Science: Vol. #42, 593-595.

Kynard, B. and E, Theiss. 2033. Spatial distribution and jumping of juvenile shads in the Connecticut River, Massachusetts during seaward migration. Journal of Ichthyology Volume 43, Supplement 2, S228-S236.

McCormick, S. D., R. A. Cunjak, B. Dempson, M. F. O'Dea, and J. B. Carey. 1999. Temperature-related loss of smolt characteristics in Atlantic salmon in the wild. Canadian Journal of Fisheries and Aquatic Sciences, 56: 1649-1658.

Moss, S. A. 1970. The responses of young American shad to rapid temperature changes. Transactions of the American Fisheries Society, 99:2, 381-384.

Normandeau (Associates Inc.). 2003. 316(A) demonstration in support of a request for increased discharge temperature limits at Vermont Yankee Nuclear Power Station during May through October. Bedford, New Hampshire.

O'Leary, J. and B. Kynard. 1986. Behavior, length, sex ratio, of sea-ward migrating juvenile American shad and blueback herring in the Connecticut River. Transactions of the American Fisheries Society, 115:529-536.

Sprankle, K. 2013. Water temperature monitoring and diadromous fishes temperature concerns in the Connecticut River upstream and downstream of Vernon Dam, Vernon, Vermont - Fall 2009 through Fall 2012. U. S. Fish and Wildlife Service, Sunderland, MA.

Weitkamp, D. E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society: 109:6, 659-702.

Zydlewski, J., S. D. McCormick, and J. G. Kunkel. 2003. Late migration and sea water entry is physiologically disadvantageous for American shad juveniles. Journal of Fish Biology, 63, 1521-1537